**Materials required for alkaline oxygen furnace steelmaking**

In the basic oxygen furnace (BOF) steelmaking process， the following types of materials are required to produce liquid steel (Figure 1)

Basic raw materials， such as hot metal， steel scrap and lime

Secondary raw materials， such as deoxidizer and carburizing agent.

Utility gases， such as oxygen， nitrogen and argon

Refractory materials and refractory materials， such as lining materials， gunning materials and repair materials

Consumable probes， such as temperature probes and sampling probes

Cooling water for cooling oxygen blowing guns and exhaust gases.



Basic raw materials

The basic raw materials required to make steel in the converter include (i) hot metal from the blast furnace， (ii) scrap and/or any other metallic iron source， (iii) iron ore， and (iv) melt. The scrap from the scrap box is the first material to be loaded into the converter. The hot metal is then poured into the converter from the hot metal charging ladle， after which the oxygen blowing begins. Flux， usually in block form， is injected into the converter via a bin system after the start of the oxygen blowing. Flux can also be injected as a powder into the furnace through the bottom spout. The composition and quantity of the basic raw materials used in the converter of a steel mill vary from mill to mill， depending on their availability and the economics of the process.

Hot metal or liquid iron is the main source of iron units and energy. Hot metal is received from the blast furnace in the form of open ladles or torpedo cars. In the case of open ladles， the hot metal is poured into a hot metal mixer to maintain its temperature and then used in the converter. The chemical composition of the hot metal can vary widely， but typically contains about 3.8% to 4.5% carbon， 0.5% to 1.5% silicon， 0.25% to 1.5% manganese， 0.05% to 0.15% phosphorus， and 0.03% to 0.08% sulfur.

In hot metal desulfurization plants， the sulfur content of the hot metal can be reduced to 0.001%. The composition of the hot metal depends on the practice and charge in the blast furnace. In general， when the blast furnace is operated in a cold state， the silicon content of the hot metal decreases and the sulfur content increases. If the phosphorus content in the blast furnace charge is high， the phosphorus content of the hot metal increases.

Carbon and silicon are the main contributors to the energy. The hot metal silicon affects the amount of scrap that can be loaded in the converter heat. For example， if the hot metal silicon is high， more heat will be generated due to its oxidation and therefore more scrap can be added to the heat. Hot metal silica also affects the amount of slag and thus the consumption of lime and the production of iron.

Hot metal is usually saturated with carbon and its carbon concentration depends on the temperature and the concentration of other solute elements (e.g. silicon and manganese). The carbon content of hot metal increases with increasing temperature and manganese content and decreases with increasing silicon content.

Knowing the temperature and carbon content of the hot metal as it is poured into the converter is important for process control of the converter. The temperature of the hot metal is usually measured in the ladle before the hot metal is loaded into the converter. Typically， the temperature of the hot metal is between 1300 degrees C and 1350 degrees C.

The high temperature and low oxygen potential favor desulfurization. In addition， the presence of other solute elements in the hot metal， such as carbon and silicon， increases the sulfur activity， which in turn enhances the desulfurization. Thus， in BOF converters， the low oxygen potential and high carbon and silicon content make the conditions more favorable for desulfurization from the hot metal rather than from the steel. Not all hot metals can be desulfurized. Hot metal used to make steel grades with stringent sulfur content is desulfurized in hot metal desulfurization plants， where desulfurization reagents can reduce sulfur in hot metal to 0.001%， but more often between 0.004 % and 0.005%. It is important that the slag produced after hot metal desulfurization is effectively removed by skimming. This slag contains a large amount of sulfur and any slag brought into the BOF will result in an increase of the sulfur content in the steel because the conditions in the BOF are not conducive to desulfurization.

Before pouring the hot metal into the BOF converter， it is weighed with a scale. It is very important to know exactly the weight of the hot metal because any error can cause problems with the chemistry， temperature and heat magnitude in the converter. This weight is also an important input to the electrostatic charge model.

Scrap is the second largest source of iron units in a coke oven converter after hot metal. Scrap is essentially recycled iron or steel， either generated within the steel plant (e.g.， CCM crop， mill scrap， scrap recovered from steel smelter scrap， or repair scrap) or purchased from outside sources.

It is important that the various types of scrap are loaded into the scrap bins in the correct quantities to meet the scrap mix requirements. The scrap bins are weighed to know the exact amount of scrap in the bins. Scrap mix and scrap weight are important parameters; otherwise they can adversely affect the heating performance in the converter.

Generally， the lighter scrap is loaded in the front and the heavier scrap is loaded at the back end of the scrap bin. This results in the lighter scrap falling first into the BOF converter when the scrap box is tilted. It is preferable for the lighter scrap to fall on the refractory lining first， followed by the heavier scrap， to minimize its impact and thus damage to the refractory lining. Also， since heavier scrap is more difficult to melt than lighter scrap， it is best to place it on top so that it is closest to the area of the oxygen injection and thus can melt faster. Scrap that is too large to fit in the furnace is cut into smaller pieces by shears， flame cutting or by an oxygen lance. Thin and small scrap， such as shears and punches， are compressed into bales with special hydraulic presses. Typically， larger， heavier scrap is more difficult to melt than lighter， smaller scrap. Scrap that is not melted can cause major problems in process control. It can lead to high temperatures or missed chemical components during the converter.

Combined blowing practices in the BOF converter can significantly improve the mixing characteristics and thus the melting of large scrap. Certain elements in the scrap， such as copper， molybdenum， tin and nickel， enter the converter through the scrap charge. These elements cannot be oxidized and therefore cannot be removed during the blowing of the converter heat. During the oxygen blowing process， these elements are uniformly dissolved in the liquid bath. Certain other elements， such as aluminum， silicon and zirconium are present in the scrap and can be completely oxidized and incorporated into the slag during the blowing process. Elements that belong to intermediate categories in terms of reaction tendency， such as phosphorus， manganese and chromium， will be distributed between the metal and the slag. Zinc and lead are mostly removed as vapor during the blowing of BOF heat. Steel smelters typically use between 10% and 35% of their total metal charge as scrap， depending on local conditions and economics. Technically， the percentage of scrap hot metal in the BOF metal charge depends on factors such as the temperature of the silicon， carbon and hot metal， and the use of post-combustion lances.

Direct Reduced Iron (DRI) is used in some steel smelters as a coolant as well as a source of iron units.DRI typically contains about 89% to 94% total iron (about 88% to 96% metallized)， 0.1% to 4% carbon， a mixture of 2.8% to 6% alumina and silica， 3% to 8% iron oxide and small amounts of calcium oxide and magnesium oxide.DRI may contain 0.005% to 0.09% phosphorus， 0.001% to 0.03% sulfur and low concentrations of nitrogen (usually less than 20 ppm).

DRI usually enters the BOF in block or lump form and measures approximately 25 mm to 30 mm. DRI blocks are passivated to eliminate any tendency for spontaneous combustion so that they can be easily handled in the steel melting shop. DRI is usually fed to the converter through a bin system.

In some steel smelters， pig iron is also used as a source of iron units. Pig iron requires heat to melt and once it is melted， it behaves as hot metal in the converter. Pig iron is loaded into the converter through the scrap bin along with other mixed scrap.

Iron ore is usually added to the BOF converter as a coolant in lump form and it is often used as a scrap substitute. Iron ores are useful scrap replacements because they contain less residual elements such as copper， zinc， nickel and molybdenum. The cooling effect of iron ore is about three times higher than that of steel scrap. The reduction of iron oxide in ore is endothermic and when iron ore is used for cooling， more hot metal and less scrap is required. Iron ore is to be loaded at the beginning of the blowing process， when the carbon content of the liquid bath is higher， in order to effectively reduce the iron oxide in the iron ore. The reduction of iron oxide in the ore produces a large amount of gas and therefore increases the tendency of the slag to foam and tilt. Late addition of iron ore can adversely affect the iron yield and the chemistry of the end slag. If iron ore is only used as a coolant prior to converter heating， the slag becomes highly oxidized and fluid， increasing the likelihood of slag entering the ladle. The delay in the cooling reaction of the unreduced iron ore leads to a sudden drop in temperature or a violent ladle reaction， resulting in excessive oxidation of the steel.

In BOF converters， a moderate amount of grinding chips can be used as a coolant. Mill chips have been found to be very effective in improving the hot metal to scrap ratio. However， it can cause severe slippage during processing. During the main blowing process， the grinding chips and other iron oxide additions are reduced， releasing iron and oxygen. This additional oxygen is available for decarburization， which accelerates the overall reaction. The tilting may be caused by the increased slag volume and increased reaction rate due to the use of more hot metal (more amounts of silicon and carbon to produce more SiO2 and CO， respectively).

In the converter steelmaking process， the consumption of calcined lime depends on the hot metal Si， the ratio of hot metal to scrap in the converter charge， and the initial (hot metal) and final (steel destination) sulfur and phosphorus content. Calcined lime is produced by calcination of limestone. The quality of calcined lime required for steelmaking in the converter is described in a separate article，.

Since a large amount of calcined lime is injected into the converter in a short period of time， careful selection of the quality of the lime is very important to increase its solubility in the slag. In general， small pieces of lime with a high porosity have a higher reactivity and promote a faster slag formation. The most common quality problems of calcined lime are uncalcined cores， hydration， excessive fines and too low reactivity.

Calcined dolomite is added together with calcined lime to saturate the slag with magnesium oxide and to reduce the dissolution of magnesium oxide from the refractory in the furnace into the slag. Typically， calcined dolomite contains about 36% to 40% magnesium oxide and 54% to 58% calcium oxide. Calcined dolomite should be added to the converter bath in such a way that the magnesium oxide content of the slag is kept above the saturation limit. The magnesium oxide level of the slag above the saturation limit makes the slag less corrosive and reduces/eliminates the chemical attack of the slag on the refractory.

In some steel smelters， raw dolomite is added directly to the converter. This serves as a source of coolant and magnesium oxide to saturate the slag， but has a delayed effect because the calcination reaction takes place in the converter. When the raw dolomite is heated， an endothermic calcination reaction occurs， resulting in a temperature drop in the converter.

Calcined dolomite is also added to the slag in order to condition the slag prior to sputtering. It is important to control the chemical composition and size of the calcined dolomite.

In some converter shops， limestone or raw dolomite is often used as a coolant rather than a flux. Limestone is often used to cool the melt pool if the converter temperature is higher than the specified target. When limestone is heated， an endothermic calcination reaction occurs， producing calcium oxide and carbon dioxide， resulting in a temperature drop in the converter. The degree of temperature drop before the converter depends on the amount of heat and the condition of the slag. For example， in a heating scale of 150 tons， the addition of 1 ton of limestone causes the temperature of the melt pool to drop by about 12 degrees Celsius.

Calcium fluoride or fluorspar (CaF2) is a slag fluidizer that reduces the viscosity of the slag. When added to BOF， it promotes rapid lime dissolution in the slag by dissolving the dicalcium silicate (2CaO.SiO2) layer that forms around the lime particles， thereby retarding the dissolution of lime in the slag. Today， fluorite is used very sparingly because it is highly corrosive to all types of refractory materials， including BOF converters and ladles. In addition， fluoride forms strong acids in the waste gas collection system and corrodes structural components， which is also an undesirable emission.

Secondary raw materials

Secondary feedstocks are deoxidizers and carburizers. These are usually added to the ladle during the extraction of heat from the converter.

Deoxidation is the final stage of steelmaking. During the steelmaking process， the molten steel exiting the ladle contains 400 to 800 ppm of reactive oxygen. Deoxidation is carried out during the steel exit process by adding appropriate amounts of ferroalloys or other special deoxidizers to the ladle.

The deoxidizers are usually bulk ferroalloys such as ferrosilicon， ferrosilicon manganese and ferromanganese. They are used in steelmaking to deoxidize as well as to introduce alloying elements. They are the most economical way to introduce alloying elements into steel. Ferroalloys give a unique quality to steel.

Iron alloys are also added to control grain size as well as to improve the mechanical properties of the steel. Depending on the steelmaking process and the type of steel being made， the requirements for different iron alloys vary considerably. Adding iron alloys to steel increases its resistance to corrosion and oxidation， improves its hardenability， tensile strength at high temperatures， wear resistance with the addition of carbon， and increases other desirable properties of the steel， such as creep strength. Ferroalloys are an important input for the production of all types of steels. They are used as raw materials for the production of alloy steels and stainless steels.

Liquid steels are also recarburized if the carbon content of the steel is below specification at the end of the blowing process. This is done by controlled addition of a carburizing agent to the ladle. Common carburizing agents are coke breeze and petroleum coke.

However， large additions in the ladle have a detrimental effect on the temperature of the steel.

Utility gases

In the converter steelmaking process， water-cooled lances are used to inject oxygen into the liquid bath at a very high rate to produce steel. With the increasing demand for the production of higher quality steel with lower impurity content， it is necessary to provide oxygen of very high purity. Therefore， the oxygen used for steelmaking must be at least 99.5% pure， preferably 99.7% to 99.8% pure. The remainder is 0.005% to 0.01% nitrogen and the rest is argon.

In the BOF converter， oxygen is injected at supersonic speed (Mach number > 1) with convergent/divergent (Laval) nozzles at the top of the water-cooled lance. The powerful gas jet penetrates the slag and impinges on the liquid metal surface， thus refining the steel. Today， most converter lances contain four to five nozzles with oxygen flow rates ranging from 640 N cum/min to 900 N cum/min.

Nitrogen is commonly used in BOF converters for combined blowing and slag sparging. The nitrogen required to improve the mixing of the metal bath is blown through a pot nozzle or permeable element mounted at the bottom. Mixing of the bath is performed with nitrogen in the high carbon range of the melt bath. The flow rate at the bottom is typically below 0.2 N Cum/t minute. In typical practice， nitrogen is introduced through the bottom during the first 60 to 80 percent of the oxygen blow. The rapid evolution of CO gas in the first part of the oxygen flow prevents the absorption of nitrogen in the steel.

Nitrogen is also used to splash the conditioned liquid slag onto the converter walls after the heat has been extracted from the converter in order to form a protective slag coating on the refractory.

Argon is commonly used for combined blowing in BOF converters. The argon required to improve the mixing of the metal bath is blown through a pot nozzle or permeable element mounted at the bottom. Mixing of the bath is carried out with argon in the low carbon range of the melt bath. The flow rate at the bottom is typically below 0.2 N Cum/t minute. In typical practice， argon is introduced through the bottom during the last 20 to 40 % of the oxygen blow.

Refractories and refractory materials

Three types of refractory materials are required for steelmaking in the converter. They are basic bricks， usually magnesium oxide carbonaceous refractories， magnesium oxide based gunite for shelling of damaged parts of the refractory， and repair materials (usually broken old bricks) for repairing erosion at the bottom of the converter.

Consumable Probes

The consumables required for converter steelmaking are disposable probes for sampling the steel for analysis at the end of blowing， and for measuring the hot metal in the hot metal charging ladle and the temperature of the steel in the converter at the end of blowing.

Cooling water

In the steel production in the BOF converter， water is needed to cool the oxygen blowing lance and nozzles， as well as to cool the exhaust gases.

To prevent the oxygen blowing lance from burning in the converter， cooling water is needed in the oxygen blowing lance. Both the copper gun nozzle and the steel gun are cooled by circulating water at a pressure of about 6 kg/cm2. An important part of the gun is the water cooling channel， where cooling water flows through the center of the nozzle and out through the outer tube of the gun. It is designed to obtain maximum cooling water velocity in the nozzle area， which is exposed to the highest temperatures. The cooling water is critical to maintaining a high gun life. The flow rate needs to be maintained at the design rate. The cooling water outlet temperature must not exceed 60 degrees Celsius to 65 degrees Celsius.

The CO-rich gas from the converter is first indirectly cooled in the converter hood by means of cooling water or an evaporative cooling system (ECS)， which reduces its nominal temperature from 1600-1700 degrees Celsius to about 900 degrees Celsius.

In some steel melting plants， the top cone of the converter is water cooled. Two components of the top cone of a steel mill converter can benefit from water cooling as a means of keeping its operating temperature low: the cone shell itself and the lip ring at the top corner of the cone.

The quality of the water is an important parameter. If the water is contaminated with oxides or dirt， deposits usually form in the pipes， which adversely affect the heat transfer.